PATENT SPECIFICATION (11) 1 596 298

1 596 298

(21) Application No. 14783/77 (22) Filed 7 April 1977
(23) Complete Specification filed 4 April 1978
(44) Complete Specification published 26 Aug. 1981
(51) INT CL[3] A61B 5/08
(52) Index at acceptance
G1N 19B1B 19B2F 19D12F0 19X5 1D3 1E 30P5 30PX 30R 4B 7N AEC

(19)

(72) Inventors FRANK DUDLEY STOTT
HERMAN LANIER WATSON and
MARVIN ARTHUR SACKNER

(54) METHOD OF AND APPARATUS FOR DETECTING OR MEASURING CHANGES IN THE CROSS-SECTIONAL AREA OF A NON-MAGNETIC OBJECT

(71) We, P. K. MORGAN LIMITED, a British Company of 10 Manor Road, Chatham, Kent, ME4 6AL, do hereby declare the invention, for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method of and apparatus for detecting or monitoring changes in the cross-sectional area of a non-magnetic object, and has particular application to the detection of respiration in human and non-human animals. The invention was devised to detect and monitor respiration in humans, particularly critically ill patients in intensive care units.

Most methods used in the past involve the use of face masks or mouthpieces, which is not only invasive and discomforting to the patient, but also disturbs the very breathing patterns being measured. These prior art methods may require cooperation from the patient, impossible if the patient is critically ill or perhaps comatose, and mouthpieces may not be left in place for continuous monitoring. Other prior art methods which are less disturbing for the patient and his breathing pattern, such as use of the pneumograph, are incapable of providing data of sufficient accuracy for clinical use.

One prior art approach measured changes in the thickness of the chest by placing coils on the front and back, sending an alternating current through one coil, and detecting the voltage induced in the other coil. The equipment used was somewhat bulky, and the linear changes in chest thickness did not represent breathing volumes very well. It did have the advantage of not requiring face masks or mouthpieces, however.

According to one aspect of the invention there is provided a method of detecting changes in the cross-sectional area of a non-magnetic body, comprising looping an extensible electrical conductor in close encirclement around said body and detecting changes in the inductance of said conductor loop, whereby to measure changes in said cross-sectional area.

According to another aspect of the invention there is provided a method of measuring respiration in a body of a human or non-human, comprising looping two extensible electrical conductors in close encirclement around the body at different locations, obtaining electrical signals representative of the inductances of the respective conductors and thereby obtaining measures of the cross-sectional areas of the body at the respective locations, and calibrating the electrical signals such that their sum provides a measure of respiration of the animal.

According to a further aspect of the invention apparatus for detecting changes in the cross-sectional area of a non-magnetic object comprises a loop of flexible and elastically extensible material of a shape and size to encircle the body and conform to the shape of the body throughout changes in the cross-sectional area thereof, an electrical conductor which is attached to the loop in such manner as to encircle the body and which is shaped so as to be extensible with the material, whereby changes in said cross-sectional area effect changes in the inductance of the conductor, and detecting means operative to detect changes in the inductance of the conductor and thereby detect changes in the cross-sectional area of the non-magnetic body.

According to yet a further aspect of the invention there is provided apparatus for measuring respiration in a body of a human or non-human animal, comprising flexible and elastically extensible material for looping around the body so as to conform to the shape of the body during respiration,

two electrical conductors which are attached to the elastically extensible material to encircle the body at two different locations and which are shaped so as to be extensible with the elastically extensible material, means for measuring the inductances of the conductors thereby providing electrical signals indicative of the respective cross-sectional areas embraced thereby, means for weighting or calibrating said electrical signals and means for summing the weighted or calibrated electrical signals such that their sum provides an accurate indication of respiration volume.

The shortcomings of prior art measurement of respiration are overcome by the discovery that clinically accurate data on breathing volumes can be derived from continuous measurements of the cross-sectional areas of the upper chest and the lower abdomen, and that each of these areas can be measured by measuring the inductance of an extensible conductor looped about the torso at each location.

The volume of a breath is equal to a corresponding change in the compartmental volume of the torso when that breath is taken. Further, this change in compartmental volume has been found to be fairly accurately represented by a corresponding change in the cross-sectional area of the chest during that breath, which can be measured. If the patient remains in one body position, such as sitting, there will be a fixed proportion between measured area change and volume of breath. However, if the patient stands up, or lies down prone, this fixed proportion changes, and must be found all over again for each new body position.

The Applicants have found a way to avoid the necessity of calibrating area change to breath volume for each and every body position. Two measurements of cross sectional area change are preferably used, one for the upper chest, the other for the lower abdomen. Then, if a ratio or relative weighting factor for the importance of chest area change relative to abdomen area change is determined for a given patient, with usable clinial accuracy the compartmental volume change and so respiration volume can be found from the two area changes, properly weighted. One ratio, one weighting factor, has been found to be clinically accurate for all positions assumed by the patient. The ratio can be determined from measurements made in each of any two body positions, and will be good for all positions. One only need measure breathing volume by some direct method, while at the same time measuring the two area changes, for the first position, then repeat the measurements for the second position. The weighting factor and the proper factor to convert to breathing volume are then easily calculated, or can be set by the apparatus in a foolproof calibration step.

To measure the change in cross sectional area, an insulated wire formed to permit body extension is wrapped about and held closely encircling the torso, and its inductance is read out continuously by making this insulated wire loop the inductance in a variable frequency LC oscillator. The oscillator is in turn connected to a frequency-to-voltage converter, which is connected to a scaling amplifier, which in turn is connected to a digital voltmeter.

When two calibrating measurements are taken, of both chest and abdomen, the corresponding scaling amplifiers are set during the calibration procedure (mentioned above) to the ratio of relative weight then found, and connected to a summing amplifier, which in turn is connected to a digital voltmeter or other display.

Since changes in area enclosed by a conductor loop result in proportional changes in inductance of that loop, it can be seen that changes in the output display by the digital voltmeter will, after calibration, represent breathing volumes. A recorder can be used with or in place of the digital voltmeter, to provide a fixed record for later analysis.

In the drawings:

Fig. 1 illusrates an extensible electrical conductor loop attached to a tubular stretch bandage in the form of a sleeveless sweater worn by the patient so the loop is held in close encirclement about the patient's torso while the patient breathes;

Fig. 1A is an enlarged view showing how the extensible electrical conductor is formed from insulated wire in alternating looplets advancing in a plane to permit extension during breathing, and is attached to the tubular stretch bandage by stitches;

Fig. 1B is an enlarged view which shows the insulated wire formed in planar advancing looplets;

Fig. 1C is an enlarged view which shows the insulated wire formed in an advancing three-dimensional coil;

Fig. 2 shows two separate extensible electrical conductor loops attached to elastic tubes in place about the patient's upper chest and lower abdomen;

Fig. 2A is an enlarged view showing the insulated wire attached by stitches to an elastic band which is a tubular stretch bandage;

Fig. 2B shows the insulated wire formed in alternating looplets advancing in a plane

and attached to a tubular stretch bandage by an adhesive or by heat sealing;

Fig. 2C is an enlarged view of the fabric of the tubuler stretch bandage;

Fig. 2D shows the insulated wire formed in alternating looplets advancing in a plane and attached to a perforated band of elastomeric material by cementing;

Fig. 2E shows an alternative version of the elastic tube with a conductor mounted, which can be opened like a belt, wrapped about the patient, and fastened together.

Fig. 3 is a block diagram of apparatus for producing electrical output signals representing chest area and abdomen area;

Fig. 3A is a circuit diagram of one embodiment of the apparatus of Fig. 3;

Fig. 3B is a circuit diagram of a second embodiment of the apparatus of Fig. 3;

Fig. 4 is a block diagram of an apparatus for receiving electrical signals from the apparatus of Fig. 3 and from a spirometer which directly measures volumes of breath, calibrating and adjusting one relative to the other, summing the chest and abdomen signals, and displaying signals on a digital voltmeter or a graphic recorder. Placement of an optional magnetic tape recorder, or an optional preprocessor unit, is indicated by a dashed box;

Fig. 4A is a circuit diagram of one embodiment of a scaling amplifier for use in the apparatus of Fig. 4;

Fig. 4B is a circuit diagram of one embodiment of a summing amplifier for use in the apparatus of Fig. 4; and

Fig. 4C is a circuit diagram of one embodiment of a voltage reference for use in the apparatus of Fig. 4.

Detailed Description of the Embodiments

The starting point in the inventive apparatus is an electrically conductive loop which is held closely around a body portion being measured. Changes in the area enclosed by this loop result in proportional changes in the inductance of the loop, a property which is measured and displayed by circuits and apparatus to be described later. The extensible conductor is formed preferably by affixing the conductor to an extensible carrier as will be described below.

The preferred carrier for holding the conductive loop closely about a body portion is a tubular stretch bandage, as described, for example, in U.S. Patent Nos. 3,279,465 and 3,307,546, both granted to V. Cherio et al, the disclosures of which are incorporated by reference in their entireties. These tubular bandages may be obtained in the form of a garment similar to a pullover sweater, or in tubes of any desired diameter and length in sizes to fit any portion of the anatomy. They are knitted in a relatively open pattern permitting free passage of perspiration, and are soft and freely stretchable, and so are comfortable to wear and permit free movement.

The electrically conductive loop is formed preferably from insulated multi-stranded wire of small gauge, shaped and attached to the tubular bandage in such a way as not to appreciably change the wearing comfort and free movement permitted by the bandage. Similarly, any electronic circuit modules usd with the loop and mounted on the bandage are kept small and placed where they will be least obtrusive.

Fig. 1 shows a tubular stretch bandage in the form of a long sleeveless sweater 1, worn closely fitted over the torso of a human being 10. Here the conductor 2 has been attached to the sweater in a number of turns around the torso from the lower abdomen to the upper chest, and so will provide a measure of area averaged over the entire torso. More turns may be placed over one portion of the torso and fewer over other portions, if it is desired to give greater weight to changes in area of one portion of the torso relative to others. This multi-turn loop is closed by a vertical section 3 returning to the starting point. Both ends of the loop are electrically connected to an electronic circuit module 4, to be described later, which is shown by way of illustration to be placed at the starting point, on the patient's lower right side. A small cable 23, comprised of insulated wires 5, 6 and 7 and ground wire 0, is shown leading away from the circuit module 4, for electrical connection to the rest of the electronic circuitry, described later.

There are a number of alternative ways of forming the conductor 2 and attaching it to the fabric of the tubular stretch bandage 1. As can be seen in the enlarged view of Fig. 1A, the fabric is comprised of heavier, inelastic yarns running generally vertically, and lighter, elastic yarns which follow a zig-zag pattern between the inelastic yarns. The electrical conductor is formed in alternating up and down looplets advancing in a plane. It is attached to the fabric of bandage 1 at points of crossing of the inelastic yarns, by stitches 8 of elastic thread tied to the inelastic yarns.

Fig. 1B shows an alternative forming of the conductor 2 into planar advancing looplets, the bandage 1 and the method of attachment thereto by stitches 8 being the same as in Fig. 1A. Fig. 1C shows yet another alternative form of conductor 2, in a small three dimensional advancing coil, again with the same bandage 1 and the same attachment to the inelastic yarns of the

fabric of the bandage by stitches 8 of elastic thread.

Fig. 2 shows a generalized view of the preferred embodiment of the present invention, showing two elastic tubes 17 and 18, in place, respectively, about the upper chest and the lower abdomen of a patient 10. Conductor 19 is mounted in a single turn loop circumferentially of tube 17, and conductor 20 is similarly mounted about tube 18. Conductors 19 and 20 are both formed in advancing up and down looplets advancing in a plane. Tube modules 9 and 21, and cables 24 and 25 extending therefrom and the wires of which they are comprised, are shown in their preferred placement on the patient's right side, and are not discussed further here, being described with the electronic circuitry later.

Alternative embodiments for elastic tubes 17 and 18, for details of the forming of conductors 19 and 20, and for the attachment of conductors 19 and 20 to elastic tubes 17 and 18, are shown in Figs. 2A, 2B, 2C and 2D, all of which show only elastic tube 17. In each embodiment, elastic tube 18 and its conductor 20 and attachment thereof may be the same as shown for elastic band 17, although it may be any of the variants described, as well.

In Fig. 2A elastic tube 17 is shown as being the preferred tubular stretch bandage. Conductor 19 in this embodiment is stitched to the inelastic yarns of the fabric of the tubular stretch bandage 17 by stitches 22 of elastic thread.

The preferred combination of all features of the elastic tubes with mounted conductors is shown in Figs. 2B and 2C. Fig. 2B shows the preferred geometry of the extensible electrical conductor, formed in alternating up and down looplets advancing in a plane. The pitch A is approximately 2-1/2 inches, the amplitude B approximately 4-1/2 inches, and the width C of the elastic tube approximately 5-1/2 inches. Fig. 2C shows an enlarged view of the fabric of the preferred tubular stretch bandage.

Conductor 19 may be attached to tubular stretch bandage 17 by an adhesive. The preferred attachment is, however, by heat sealing. For this the preferred wire is 28 gauge stranded copper, the preferred insulation is teflon or PVC. The insulated wire is given a precoat of a liquid plastics material such as polyurethane, polyamid or polyester chosen for compatibility with the wire insulation and for adequate heat sealed adhesion to the rubber-textile stretch bandage.

The mode of heat sealing may be conventional, and is done with the elastic tube stretched to the chest or abdomen size intended, a variety of sizes being contemplated for the variety of sizes of human beings. The heat sealing may be done one section at a time, depending upon the equipment available, and, similarly, may be done first down the middle of the band, and secondly along the upper and lower sides. The heat cycle time and temperature is a function of the materials chosen, and will be within the ability of persons of ordinary skill. With the material expressly disclosed, each heat seal cycle is between about 10 and 20 seconds, at a temperature sufficient to accomplish adhesion with the precoat employed.

Fig. 2D shows an alternative embodiment, in which tube 17 is made from an elastomeric material such as rubber, to which conductor 19 is cemented with a rubber type cement compatible both with the insulation on the wire and the elastomeric material. To make the tube more comfortable, holes may be provided as, for instance, in the pattern shown and of about 3/8 inch diameter, so located as not to interfere with the path of the wire, as shown. The looplet pitch D may be approximately 2-3/4 inches, the amplitude E approximately 1-3/4 inches, and the width F of the tube approximately 3-1/4 inches.

Fig. 2E shows an alternative embodiment of the elastic tube with mounted conductor in which the tube 26 may be opened, as for convenience in placement onto a human torso, and fastened together encircling the torso. Thus, an encircling but openable band is included in the term "tube". Snap fasteners 28 and 29 are shown holding the band together. Any standard fastener means could be used, for example, ribbon ties, hook and eyelet fasteners, Velcro strips, or Ace brand fastener clips for stretch bandages. Any of the band materials described before could be used, with knitted elastic bandage material preferred. Conductor 27 may be formed as described previously, and attached by any of the methods shown before. The ends 30 and 31 of conductor 27 may be fitted with small detachable connector plugs 32 and 33 and module 34 with matching connector sockets (not shown) for electrical connection of the conductor loop to the module. A cable 35 is provided for connecting the module 34 with the rest of the apparatus.

The starting point having been described, namely a conductive loop closely encircling a body member so that its inductance will be a measure of the cross sectional area encircled, the rest of the respiratory monitoring apparatus will now be considered. The electronics of the respiratory monitoring apparatus can be any circuit that reliably and accurately measures changes in the inductance of the conductive loop mounted on the body

encircling tube. Two loops will be provided in the preferred embodiment described in respect to Fig. 2, although a satisfactory, but less sophisticated apparatus can be formed with only one loop. Respiratory movements of the wearer result in changes in the cross-sectional areas and hence in the inductances of the loops. Once these changes in inductance are converted to an electrical signal for each loop, those signals are calibrated by the use of apparatus described hereinafter to accurately measure the volume of respiration. One apparatus for converting changes in inductance into proportional voltages is shown in Fig. 3 in block diagram form.

A variable frequency oscillator (VFO) is connected electrically to each of the two loops, 19 and 20 in Fig. 2. The resonant frequency of the variable frequency oscillators is determined by an internal capacitor and the inductance of the conductor loop to which it is attached. This frequency may, for example, be centred at about 1 MHz and varies as the coil it is connected to expands and contracts with respiration. Of course, the term coil is intended to include coils of about one turn as well as a plurality of turns. In the present embodiment, particular emphasis is placed on the minimization of artifacts caused by movement and on the reduction of parasitic capacitances between the coils and the body of the wearer. This is one reason for preferably placing the oscillator electronics on the garment itself, in modules 9 and 21 in Fig. 2.

The changes in frequency of the variable frequency oscillator are detected and converted to a DC signal by the frequency to voltage converter (FVC) which is fed by the variable frequency oscillator (VFO). The frequency to voltage converter may, for example, consist of a DC restoration circuit and a simple diode detector for conversion of the frequency. The output of the frequency to voltage converter is then connected to a signal conditioning filter (SCF). The lower and higher cutoff frequencies of this filter may, for example, be set for about .05 and 10 Hz, respectively. The signal conditioning filter is followed by a voltage amplifier (OA) to boost the output signals to an amplitude of approximately 200 mV peak-to-peak for a one to two liter breathing volume in adults. Thus, as a patient breathes to vary the enclosed area and hence the inductance of coils 19 and 20, the frequency of the signal generated by the oscillator (VFO) will vary in response thereto. This variation will be detected by the frequency to voltage converter (FVC) which will produe a signal, preferably DC, dependent upon such detected variation of enclosed area of the torso of the breathing patient. A signal conditioning filter (SCF) "cleans up" this signal, removing unwanted and extraneous high and low frequency components that may have appeared. The output of the signal conditioning filter is then amplified by amplifier OA to provide a signal output of useful magnitudes. The output signal may be employed in numerous ways hereinafter described to yield useful information through various types of readouts.

One skilled in the art can readily select standard circuits to accomplish the functions described for each of these blocks. Fig. 3A shows one such circuit, with brackets below the circuit indicating which portion corresponds to which block. Where it may be purely a matter of nomenclature to decide which portion should be assigned to a given block, overlapping brackets are drawn, indicating that one may assign the overlapping elements to either block as may suit his preferences. Fig. 3B shows an alternative circuit to perform the same function, a preferred embodiment. Typical, and presently preferred, circuit elements and values are shown on the drawings and will be readily understandable to a person of ordinary skill. One variation of the circuit shown in Fig. 3B is to combine the chest and abdomen circuits and use one LM339 quad comparator in place of the two LM393 dual comparators (one for each Fig. 3B circuit, 1/2 at each circuit position indicated) which would be required if there were no such combination. Since the circuits illustrated in Figs. 3A and 3B are of conventional design, a detailed description of their construction and mode of operation is deemed unnecessary. Numerous variations in this circuitry will readily suggest themselves to persons of ordinary skill and are within the intended scope of this invention.

The circuitry shown in Fig. 3A or in Fig. 3B may be incorporated into one module, such as module 9 in Fig. 2, which would also carry a battery (not shown) to supply the indicated voltages. Preferably, the battery and some part of the circuitry are mounted nearby but not on the tube, in order to keep the module small and of minimum burden to the patient. Thus, in Fig. 3A the module may contain up to and including the second diode IN4148 and not the 22K resistor just to its right. In Fig. 3B, the separation may be just to the left or right of the 100K resistor.

Fig. 4 shows in block diagram form an apparatus for calibration and operation, which in operation takes the chest output and abdomen output signals from the apparatus of Fig. 3 just described, and converts them to a form useful for one

observing a patient's respiration. In addition to terminals for these inputs of the output signals from chest and abdomen circuits of Fig. 3, there is provided an input terminal for a signal from a presently conventional direct respiration measuring apparatus, for example, an Ohio Medical Model 840 spirometer. This conventional apparatus provides a direct measurement of respiration volumes during calibration. A direct current reference voltage source is provided internally as shown in Fig. 4, along with suitable switches, so that during calibration either a zero (electrical ground) signal or a standard reference voltage signal can be substituted for either the chest of the abdomen output from the apparatus of Fig. 3.

A scaling amplifier is shown, next in series, in each of the spirometer, chest, and abdomen signal lines. The purpose of these three scaling amplifiers is, first, to adjust the sizes of the corresponding signals in each line so that they are of a large enough magnitude for convenient use in the equipment that follows, and second, to permit adjustment of each of the three signals to its proper relationship to the other two, during calibration. Calibration will be discussed in some detail below. The adjusted chest and abdomen signals coming from the respective scaling amplifiers are made available directly at two of the four terminals provided for connection to a display apparatus. The spirometer signal, also after adjustment by its scaling amplifier, is made available at a third terminal there, and the fourth terminal carries the arithmetic sum of the two adjusted signals for chest and abdomen, the calculation of this sum being done by the summing amplifier shown in Fig. 4. Thus, resulting adjusted signals are all made available to a display, which may be a four channel (or more) graphic recorder, or a digital voltmeter. Examples of each, respectively, are an Electronics for Medicine DR-8 with rapid writer, which records up to eight channels, and an Analogic AN2570 digital voltmeter.

Preferred embodiments of the scaling amplifier, the summing amplifier, and the reference voltage are shown in Figs. 4A, 4B, and 4C respectively. Since these circuits are of conventional design, a detailed description of their construction and mode of operation is deemed unnecessary. Numerous variations in this circuitry will readily suggest themselves to persons of ordinary skill and are within the intended scope of this invention.

It may also be useful to record the data from the chest and the abdomen on a magnetic tape recorder for later analysis, placing it in series where shown as a dashed box in Fig. 4. Any suitable unit might be used, for example, a four channel portable Oxford Medilog Cassette Recorder, which both records and plays back a number of channels of information.

The use of a portable tape recorder permits long-term data accumulation on the respiration of ambulatory patients, since all of the apparatus up to and including such a recorder can be made small, light and unobtrusive to the patient. Alternatively, radio telemetry may be used to couple the vests and related apparatus on the patient to fixed monitoring and recording equipment.

Another option is to place a preprocessor unit immediately following the scaling amplifiers. Preprocessor here means, simply, a circuit which does some simple calculation using the respiration signals. These calculations may be done manually from the recorded data, but it might be useful to a clinical physician to have the calculation results continuously, in real time, while the patient breathes. Having the respiration signals in electronic form as provided by the present embodiment makes this possible, with the use of standard circuits known to one skilled in the art. With such circuits, various types of analyses can be made on the signals such as minute volume, respiration rate, maximal voluntary ventilation and detection of obstructive and central apneas.

Apnea refers simply to a cessation of breathing, and there are two kinds. One is the obstructive apnea, caused as the name indicates by some sort of blockage of the windpipe, or of both mouth and nose. Obstructive apneas are characterized by out of phase excursion of the chest and abdominal excursions with a consequent reduction in summed breathing volume, all of which are measured and displayed by the apparatus of the present invention. The other apnea is the central apnea, in which the patient ceases any and all efforts to breathe. Central apneas are distinguished by cessation of both rib cage and abdominal movement.

Other results which may either be calculated manually from the recorded data, or obtained by a standard circuit, include time taken for inspiration, time taken for expiration, the ratio between these times, or the phase difference between chest excursion and abdominal excursion. Comparisons could be made with other sources of data, for example, heart monitors. Finally, it might prove useful to use an analog to digital converter circuit, well known in the art, in order to supply the chest and abdomen signals directly to a computer. Any of these standard circuits could be placed where the preprocessor is indicated on Fig. 4 by a dashed box.

Various other arrangements of magnetic and graphic recorders, digital voltmeters, and preprocessors, singly and in combination, will be apparent to one skilled in the art, and may be made to satisfy particular needs.

Calibration of the apparatus will now be described. Referring to Fig. 4, the scaling amplifiers must be set for each patient so that the output of the summing amplifier will always represent the same respiration volume as that measured directly by a spirometer. This may be done by trial and error as the patient assumes various body positions with both the spirometer and the inventive apparatus connected. It is faster and more convenient for the patient, however, to use the procedure which follows. Only a few breaths are needed in each of two positions, after which the spirometer can be removed. Very little cooperation from the patient is required, and, indeed, the calibration can be carried out with a critically ill or even an unconscious patient. The two body positions required may be, in such a case, supine on a bed or stretcher with the head end raised, and supine with, instead, the foot end raised. Standing and prone positions are used in the example below, but any pair of positions may be used so long as they differ in the relative chest and abdomen breathing contributions. Usually, the difference comes from shifting the weight between chest and abdomen.

The calibration procedure is:

(1) Adjust the spirometer scaling amplifier so that the signal during quiet breathing is of an appropriate magnitude for the display, for example, the graphic recorder.

(2) With the reference voltage switched in, set the respective scaling amplifiers for chest and abdomen so that the graphic recorder registers unity for each. Switch out the reference voltage.

(3) Place the patient in one position, for example, standing, and while he breaths quietly obtain a simultaneous set of numerical readings on the graphic recorder for the spirometer (V_{ss}), the chest (C_s), and the abdomen (A_s).

(4) Repeat step (3) with the patient in a different position, for example, prone, obtaining another set of numerical readings, (V_{sp}, C_p, and A_p).

(5) Find proportionality constants K_1 and K_2 so that the following equation for volume of respiration

$$V_s = K_1C + K_2A$$

can be written. One set of numerical values V_{ss}, C_s, and A_s for the standing position can be inserted and a second set of numerical values V_{sp}, C_p, and A_p for the prone position can be inserted, which will result in two equations with only the two unknowns, constants K_1 and K_2. These may be calculated from

$$K_1 = \frac{A_pV_{ss} - A_sV_{sp}}{C_sA_p - C_pA_s}$$

$$K_2 = \frac{C_pV_{ss} - C_sV_{sp}}{C_pA_s - C_sA_p}$$

by longhand, or by using a programmable calculator.

(6) Now once more switch in the reference voltage as in step (2), and reset the respective scaling amplifiers for chest and abdomen so that the graphic recorder registers the calculated number K_1 for the chest and the calculated number K_2 for the abdomen. Switch out the reference voltage. Calibration is then complete, for this patient, in any position. That is, the output of the summing amplifier will give the same reading on the display as would the spirometer. The spirometer need only be used during the calibration and may now be discarded insofar as this patient is concerned.

It is apparent that the purposes of monitoring the breathing of a critically ill patient will often include the warning that this monitoring will give to the observer that there are life threatening breathing irregularities, which require immediate medical intervention. The preprocessor may include circuitry to provide an audible or visual alarm when certain irregularities occur, to ensure that the observer takes notice.

It is also possible that less elaborate versions may prove useful in non-hospital situations. There are situations for which a single elastically deformable tube and conductive loop, rather than two, would be sufficient, and for which calibration before use would be unimportant. The electronic circuitry could also be simplified and abbreviated. For example, if there were fear of possible crib death of an infant, the so-called Sudden Infant Death Syndrome, a simple version could alert the parents elsewhere in the house, should the infant cease to breath for some set period, perhaps 20 seconds. Alternatively, a bank teller fitted with a similar apparatus could give a "silent alarm" of foul play by simply holding his breath for a brief period. In this latter alternative, the apparatus may include a radio transmitter to give the teller full mobility. This version could also prove useful for use by night watchmen.

Other applications of this invention are

(a) monitoring animal respiration in veterinary medicine or scientific studies; (b) measuring changes in area of human or animal body portions other than the torso in respiration; and (c) measuring changes in areas of non-magnetic objects which are not portions of living bodies. This last application may for example, include indicating the contained liquid volume in a plastic pouch, or gas volume in such a pouch.

It is envisaged that the invention will find application in a wide variety of circumstances in which it is desired to detect or measure changes in girth or cross-sectional area of a non-magnetic object over which an elastic sleeve carrying the inductive element can be passed. Slow changes in cross-sectional area can be detected or measured, for example to determine the growth rate of a growing body such as a vegetable marrow. Whilst the invention has been described in terms of detecting or measuring changes, in any given case detection will be quantifiably related to measurement.

WHAT WE CLAIM IS:—

1. A method of detecting changes in the cross-sectional area of a non-magnetic body, comprising looping an extensible electrical conductor in close encirclement around said body and detecting changes in the inductance of said conductor loop, whereby to measure changes in said cross-sectional area.

2. A method according to claim 1, wherein the non-magnetic body is a living body.

3. A method according to claim 2 and for detecting respiration in human and non-human animals, wherein said body is the torso of the human or non-human animal.

4. A method according to any one of the preceding claims, wherein the electrical conductor is carried by a loop of elastically extensible material which encircles the body so as to conform to the shape of the body during changes in the cross-sectional area thereof.

5. A method according to claims 3 and 4, wherein the loop is in the form of a vest and the conductor is a multi-turn coil encircling the chest and abdomen of the animal.

6. A method according to claims 3 and 4, wherein the loop is one of two such loops which respectively encircle the chest and abdomen of the animal, the conductor being one of two conductors the changes in the inductances of which are electrically combined to detect respiration.

7. A method according to Claim 5 or 6, wherein changes in the inductance of the or each conductor are sensed by electrical circuitry which produces a measurement of volumetric respiration.

8. A method according to Claim 7, wherein the electrical circuitry is calibrated, by the use of a spirometer, in each of two different positions of the animal.

9. A method of measuring respiration in a body of a human or non-human animal, comprising looping two extensible electrical conductors in close encirclement around the body at different locations, obtaining electrical signals representative of the inductances of the respective conductors and thereby obtaining measures of the cross-sectional areas of the body at the respective locations, and calibrating the electrical signals such that their sum provides a measure of respiration of the animal.

10. A method according to Claim 9, wherein said locations are around the chest and around the abdomen, respectively.

11. A method according to Claim 9 or 10, wherein calibration is effected by the use of a spirometer in such manner that said sum gives the same measure of respiration as the spirometer in each of two different postures of the animal.

12. Apparatus for detecting changes in the cross-sectional area of a non-magnetic body, comprising a loop of flexible and elastically extensible material of a shape and size to encircle the body and conform to the shape of the body throughout changes in the cross-sectional area thereof, an electrical conductor which is attached to the loop in such manner as to encircle the body and which is shaped so as to be extensible with the material, whereby changes in said cross-sectional area effect changes in the inductance of the conductor, and detecting means operative to detect changes in the inductance of the conductor and thereby detect changes in the cross-sectional area of the non-magnetic body.

13. Apparatus according to Claim 12, wherein the loop is a tubular vest and the conductor is a multi-turn coil.

14. Apparatus according to Claim 12, wherein the loop is one of two such loops and the conductor is one of two such conductors.

15. Apparatus according to Claim 12 or 14, wherein the or each loop is made of rubber.

16. Apparatus according to any one of Claims 12 to 15, wherein the or each conductor is an insulated metal wire which advances around the loop in a serpentine manner.

17. Apparatus according to any one of Claims 12 to 16, wherein the or each electrical conductor is attached to the loop by stitches, by adhesive, or by heat sealing a

thermoplastic coating of the conductor to the loop.

18. Apparatus according to Claim 12 or 14, wherein the or each loop is constituted by an elastically deformable band having first and second ends, and separable fastener means, so that the first and second ends may be joined by the separable fastener means to form the continuous loop.

19. Apparatus according to any one of Claims 12 to 18 and for recording the respiration of a human or non-human animal constituting said non-magnetic body, wherein the detecting means comprise a resonant circuit the inductive element of which is constituted by the or each conductor, and means for recording changes in the frequency of oscillation of the resonant circuit in response to movement of the torso of the animal during respiration.

20. Apparatus according to Claim 18, wherein the resonant circuit comprises, for the or each conductor, a variable frequency LC oscillator employing as inductance the corresponding conductor, a frequency-to-voltage converter, a signal conditioning filter, and a scaling amplifier; the variable frequency LC oscillator being connected in series with and feeding the frequency-to-voltage converter, the frequency-to-voltage converter being connected in series with and feeding the signal conditioning filter, and the signal conditioning filter being connected in series with and feeding the scaling amplifier.

21. Apparatus according to Claim 20, wherein there are two conductors and the signals from the two scaling amplifiers are combined to provide an output representative of volumetric respiration.

22. Apparatus according to Claim 21, wherein a magnetic tape recorder or preprocessor unit is connected to receive the outputs of the two scaling amplifiers.

23. Apparatus for measuring respiration in a body of a human or non-human animal, comprising flexible and electrically extensible material for looping around the body so as to conform to the shape of the body during respiration, two electrical conductors which are attached to the elastically extensible material to encircle the body at two different locations and which are shaped so as to be extensible with the elastically extensible material, means for measuring the inductances of the conductors thereby providing electrical signals indicative of the respective cross-sectional areas embraced thereby, means for weighting or calibrating said electrical signals and means for summing the weighted or calibrated electrical signals such that their sum provides an accurate indication of respiration volume.

24. Apparatus according to Claim 23, wherein said means for summing comprises a summing amplifier.

25. A method of detecting respiration, substantially as herein particularly described with reference to any one of the alternative embodiments shown in the accompanying drawings.

26. Apparatus for detecting respiration, substantially as herein particularly described with reference to any one of the alternative embodiments shown in the accompanying drawings.

REID CLARKE & CO.,
Chartered Patent Agents,
Craven House,
121 Kingsway,
London, WC2B 6PJ.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1981
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1596298 COMPLETE SPECIFICATION

7 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

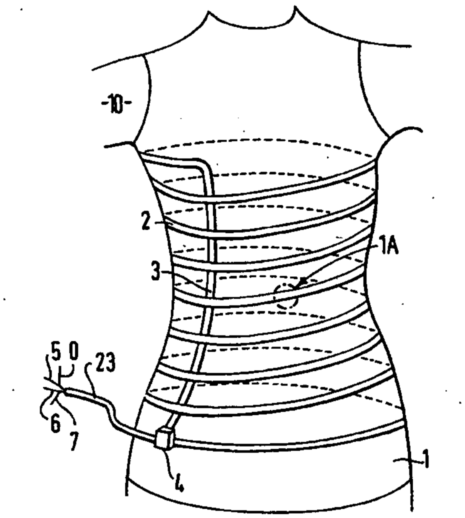


Fig.1

Fig. 2

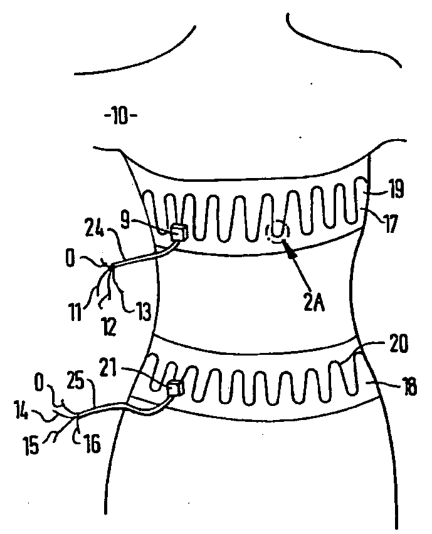


Fig.1A

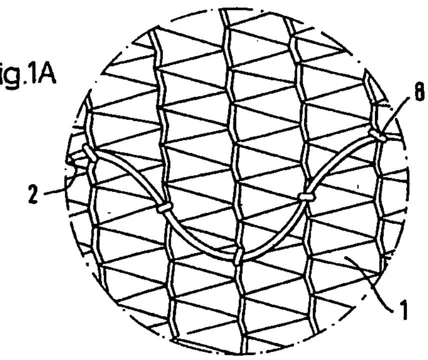


Fig.1B

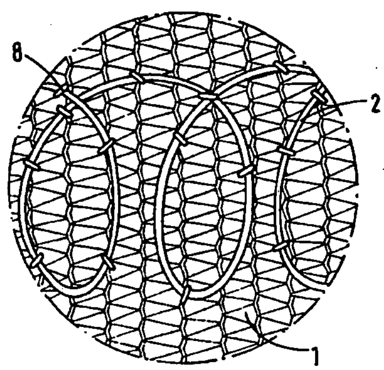


Fig.1C

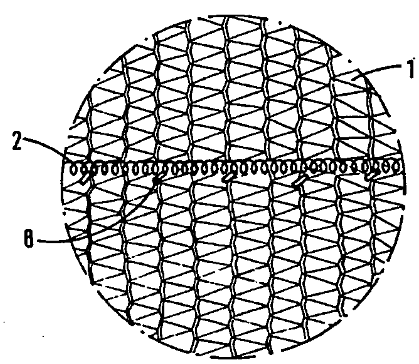


Fig. 2A.

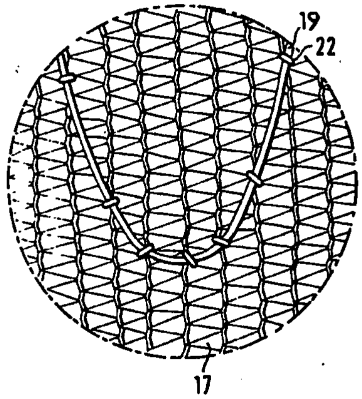


Fig. 2E.

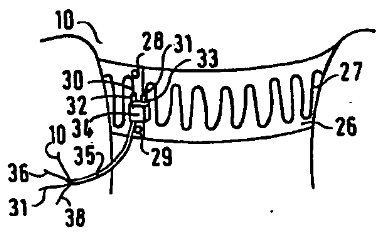


Fig. 2D.

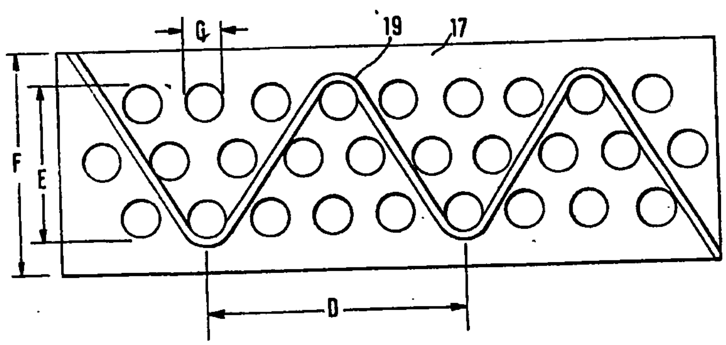


Fig. 2B

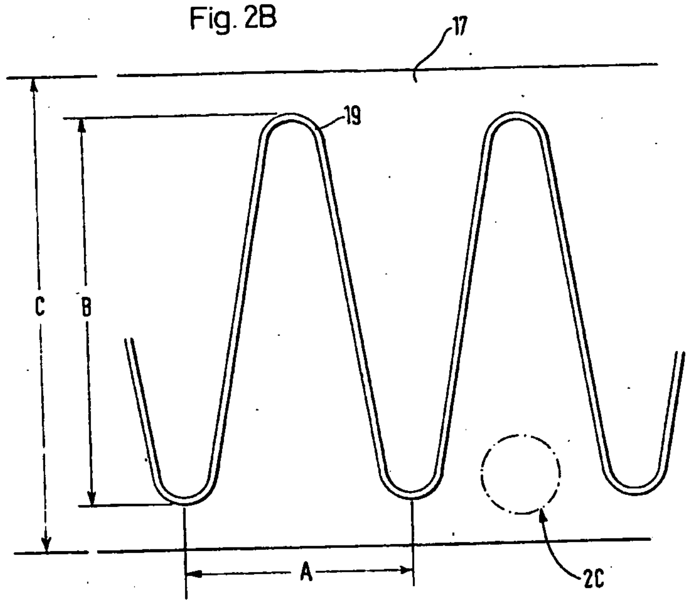
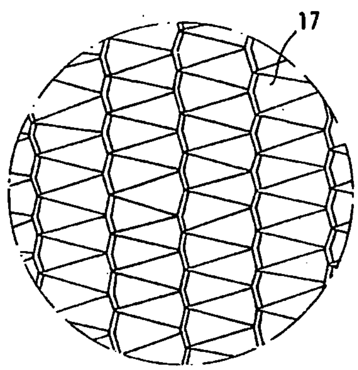


Fig. 2C



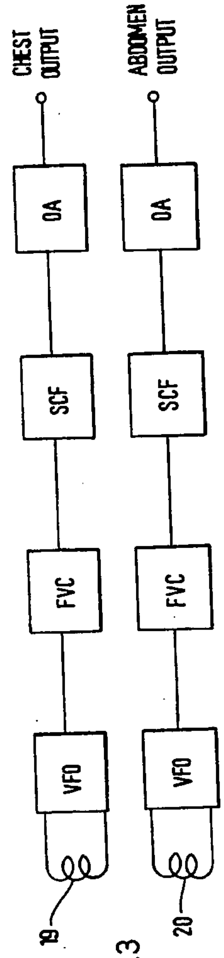

CHEST OUTPUT
ABDOMEN OUTPUT
OA
SCF
FVC
VFO
19
20

Fig.3

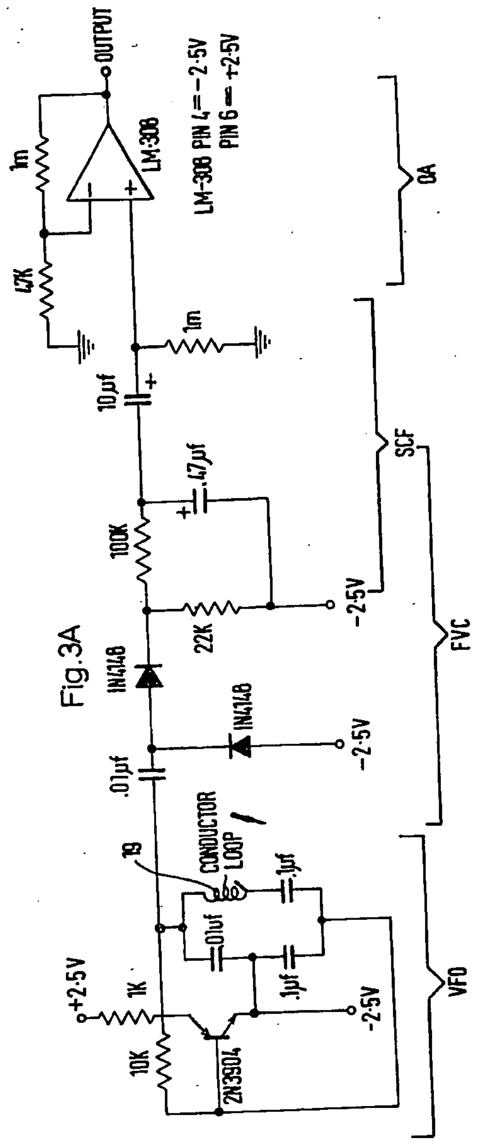

OUTPUT
LM-308 PIN 4 = −2·5V
PIN 6 = +2·5V
LM308
1m
47K
10µf
.47µf
100K
22K
−2·5V
1N4148
.01µf
CONDUCTOR LOOP
19
.1µf
.01uf
+2·5V
1K
10K
2N3904
OA
SCF
FVC
VFO

Fig.3A

Fig. 3B

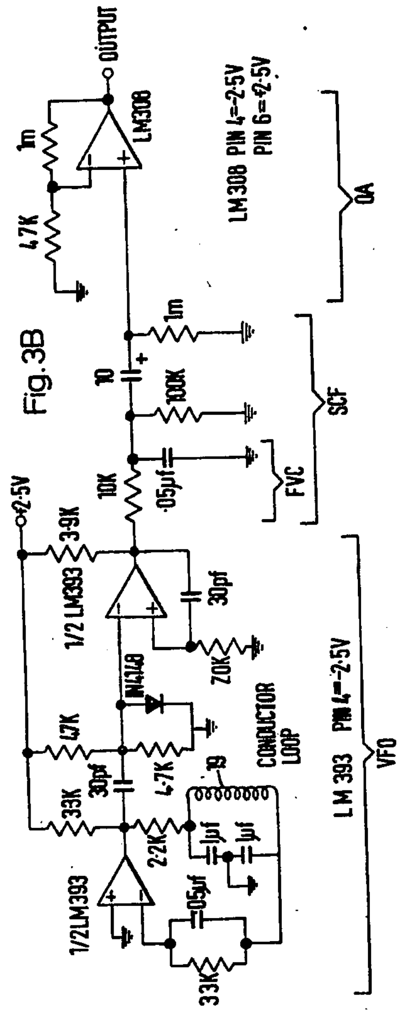


Fig. 4B

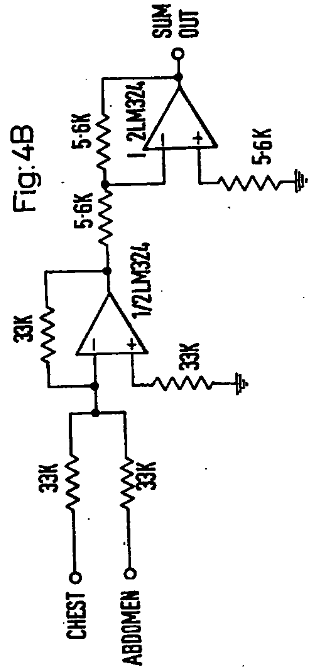


Fig. 4C

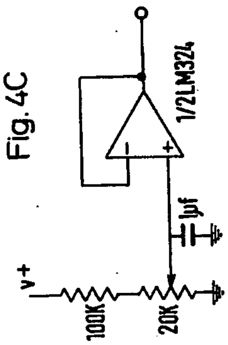
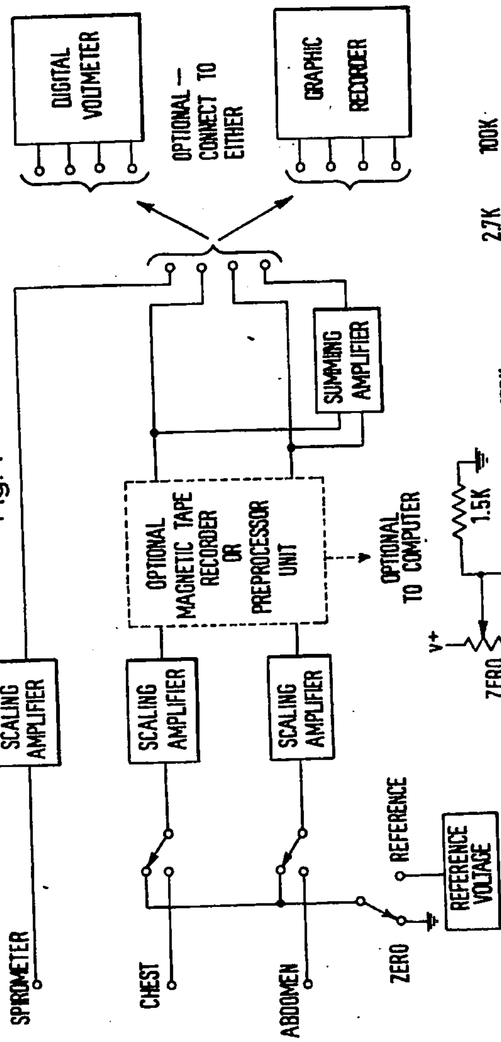


Fig. 4


DIGITAL VOLTMETER
OPTIONAL — CONNECT TO EITHER
GRAPHIC RECORDER
SUMMING AMPLIFIER
OPTIONAL MAGNETIC TAPE RECORDER OR PREPROCESSOR UNIT
OPTIONAL TO COMPUTER
SCALING AMPLIFIER
SCALING AMPLIFIER
SCALING AMPLIFIER
REFERENCE
REFERENCE VOLTAGE
ZERO
SPIROMETER
CHEST
ABDOMEN

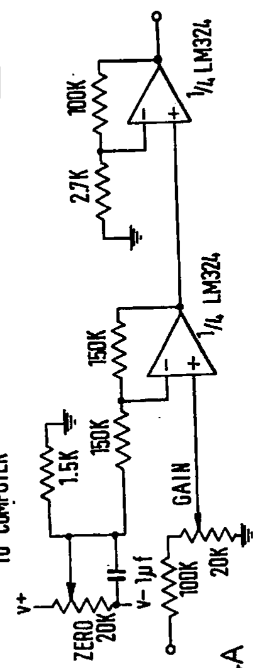

100K
2.7K
1/4 LM324
150K
1/4 LM324
1.5K
150K
GAIN
V+
ZERO 20K
V−
1μf
100K
20K

Fig. 4A